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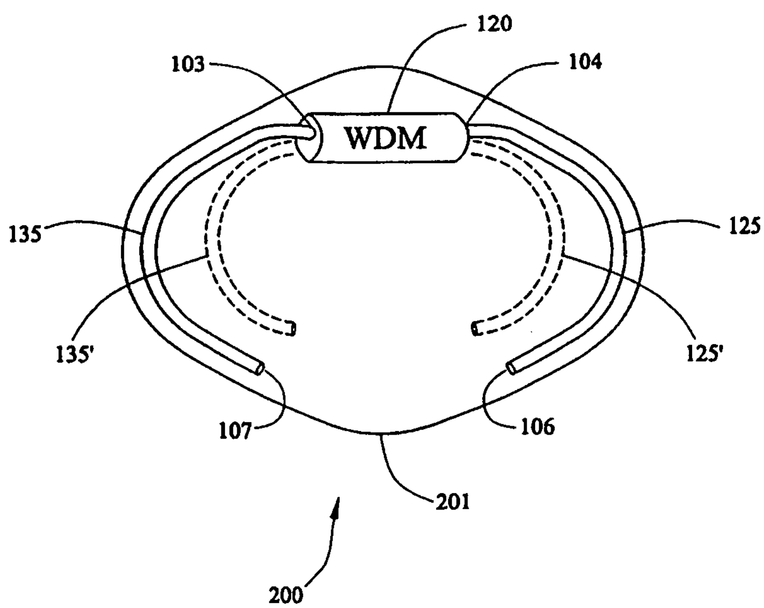

(57) Abstract

A method is disclosed which reduces wavelength ripple in a fiber optic gyroscope by suppressing, as well as reducing the effects of, whispering gallery modes generated by the gyroscope light source. The method functions to increase the radius of bends in existing curved sections of optical fiber used in the light source for a fiber optic gyroscope. This increase in bend radius effectively reduces the amount of core–to–clad–to–core reflected light, which in turn reduces the extent to which whispering gallery modes are generated, thereby reducing a source of wavelength ripple. Reduction of wavelength ripple is also accomplished in the present invention by using a band rejection filter to attenuate one of the bimodal spectral components generated by the gyroscope light source.

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FIELD OF THE INVENTION

This invention relates generally to fiber optic gyroscopes, and more particularly, to a method and apparatus for reducing wavelength ripple in light emitted from a light source in a fiber optic gyroscope.

BACKGROUND OF THE INVENTION

PROBLEM

It is a problem in fiber optic gyroscope technology to provide a light source which is sufficiently noise-free so as to enable a fiber optic gyro to sense extremely small rotation rates, with minimal spurious output due to system noise. One type of noise which is impairs gyroscope performance over a temperature range is wavelength ripple. Wavelength ripple is a periodic variation in the wavelength of a light source output as a function of temperature. In a fiber optic gyroscope, wavelength ripple over a temperature range impairs the scale factor accuracy of the fiber optic gyroscope over temperature, i.e., the relationship between the gyro input rotation rate and the output pulse rate becomes non-linear over the temperature range. It has been observed that the light emitted from certain fiber optic gyroscope light sources exhibits wavelength ripple, but the cause of the wavelength ripple, and means of suppressing it, were heretofore unknown.

SOLUTION

The present invention overcomes the foregoing problems and achieves an advance in the art by providing a method which reduces wavelength ripple in a fiber optic gyroscope by suppressing, as well as reducing the effects of, whispering gallery modes generated by the gyroscope light source.

Whispering gallery modes are caused by the transmission of light through a curved section of optical fiber. More specifically, a narrow-radius bend in the optical fiber allows some of the light traveling through the fiber core to propagate into the optical fiber cladding, i.e., some of the light leaks from the core into the optical fiber buffer, forming a secondary light path. At some subsequent point along the optical fiber, this secondary light is re-coupled back into the fiber core, where it is recombined with the primary light traveling through the core, creating whispering gallery modes in

the optical fiber core. The interaction of the secondary light with the primary light in the core generates two-beam or multiple-beam interference which causes intensity modulation of the light as a function of temperature.

Wavelength conversion of light in the fiber optic gyroscope light source creates light having a bimodal spectrum; i.e., having spectral peaks at two different wavelengths. When two temperature-caused intensity modulated light beams having different wavelengths are transmitted through an optical fiber which is subjected to a change in temperature, the light spectrum thus created has a resulting mean wavelength which exhibits a temperature-relative periodicity. Hence, intensity modulation of the light due to whispering gallery modes, coupled with the bimodal spectra generated by the light source, causes the light generated by the light source to exhibit wavelength ripple.

The present method functions to increase the radius of bends in existing curved sections of optical fiber used in the light source for a fiber optic gyroscope. This increase in bend radius effectively reduces the amount of core-to-clad-to-core reflected light, which in turn reduces the extent to which whispering gallery modes are generated, thereby reducing a source of wavelength ripple.

Reduction of wavelength ripple is also accomplished in the present invention by using a band rejection filter to attenuate one of the bimodal spectral components generated by the gyroscope light source.

BRIEF DESCRIPTION OF THE DRAWING

The invention may be better understood from a reading of the following description thereof taken in conjunction with the drawing in which:

FIG. 1 is a diagram of a fiber optic light source in accordance with the present invention;

FIG. 2 is cut-away view of a fiber optic gyroscope light source, showing a wavelength division multiplexer with optical fiber bends at the input and output thereof;

FIG. 3 is an illustration showing the creation of whispering gallery modes; and

FIG. 4 depicts a typical waveform of the light generated by the fiber optic light source after having been filtered and spectrum-shifted.

DETAILED DESCRIPTION

Figure 1 is a diagram of fiber optic light source 100, in accordance with one exemplary embodiment of the present invention, as used in a fiber optic gyroscope. As shown in Figure 1, laser 105 is a solid state (semiconductor) laser which generates light having a wavelength of 980 nm, in the near-infrared region. In operation, light emitted by laser 105 is passed through filter 110, which is a fiber Bragg grating used for stabilizing the wavelength of the light at 980 nm. The filtered light is then received by wavelength division multiplexer 120, which transmits the 980 nm light via semi-circular bend 125 into a length of erbium doped fiber 130, which converts (spectrum-shifts) the 980 nm light into light having a mean wavelength of approximately 1550 nm. This spectrum-shifted 1550 nm light, however, has a bimodal spectrum, with peaks 402 and 401 located at approximately 1531 nm and 1560 nm, respectively.

The 1531/ 1560 nm light then passes back (in the opposite direction) through wavelength division multiplexer 120, which redirects the light through semi-circular bend 135 into a length of erbium doped fiber 140 which is a filter used for spectrum shaping. Filter 140 converts a substantial amount of the 1531 nm light to the 1560 nm wavelength, but a vestigial amount of 1531 nm light is still present in the output of filter 140.

A band reject filter 150, which is preferably a fiber Bragg grating, is optionally employed concurrently with the above method to further attenuate the 1531 nm component of the light which is output from filter 140. The light output from band reject filter 150 is then transmitted through optical isolator 160 to produce fiber optic light source output 170. Attenuation of the 1531 nm spectral component 402 further reduces the amount of wavelength ripple present in the output 170 of fiber optic light source 100. It should be noted that the present method and apparatus functions to significantly reduce wavelength ripple in a fiber optic gyroscope, without the inclusion of band reject filter 150.

Figure 3 is an illustration of a section of optical fiber showing the creation of whispering gallery modes. As shown in Figure 3, whispering gallery modes are caused by the transmission of light through a curved section of optical fiber 300 in a fiber optic gyroscope. As the radius of a curve, or bend, in a section of optical fiber is decreased, there is a corresponding increase in the amount of light that is reflected from the curved section of fiber cladding back into the fiber core. More specifically, the bend in the optical fiber allows some of the light 301 traveling through the fiber core 305 to

propagate into the fiber buffer 310, at 302, forming a secondary light path. This secondary light then leaks from buffer 310 into the cladding 315 at point 303, where at some subsequent point 304 along the optical fiber, this light is reflected from the outside wall 315' of cladding 315 back into the fiber core 305, where it is recombined with the primary light traveling through the core. The recombining in the fiber core of this secondary light with the primary light in the core generates two-beam or multiple beam interference which causes intensity modulation of light beam 306 as a function of temperature.

Light having a single narrow-line spectrum would be impacted by the presence of whispering gallery modes, and exhibits intensity modulation(measured as a function of temperature), but does not exhibit a change in wavelength as a result of this interference. However, when light having a bimodal spectrum is transmitted through an optical fiber, and when both of the spectral modes exhibit intensity modulation, a light spectrum is created which has a resulting mean wavelength which exhibits a temperature-relative periodicity, or wavelength ripple.

Figure 2 is cut-away view of light source package 200, showing a wavelength division multiplexer 120 with semi-circular optical fiber sections (bends) 125,135 connected at the input 103 and output 104 thereof. Ends 106/107 of optical fiber sections 125/135, respectively, are shown as being unconnected in Figure 2, for the purpose of clarity. In accordance with an exemplary embodiment of the present invention, light source package 200 includes housing 201, wavelength division multiplexer 120 with semi-circular optical fiber sections 125 and 135 (connected to erbium doped fiber 130 and filter 140, respectively), filter 150, and optical isolator 160. In a previously existing light source package, the radius of optical fiber bends (shown as reference nos. 125' and 135' in Figure 2) was constrained, by the dimensions of the housing, to a radius of approximately 1.9 cm (centimeters). In accordance with an exemplary embodiment of the present invention, housing 120 is either increased in size, or alternatively, optical fiber sections 125 and 135 are re-routed through the housing 120 (if permitted by the housing dimensions), so that the minimum radius of optical fiber sections 125 and 135 is approximately 2.5 cm.

In a fiber optic light source having semi-circular optical fiber sections 125'/ 135' with radii of 1.9 cm, wavelength ripple was observed to be greater than 70 ppm (parts per million) over a 130 degree centigrade temperature range. When the radius of semi-circular optical fiber sections 125' and 135' was increased to 2.54 cm in accordance with

the present invention, the wavelength ripple was measured at less than 30 ppm over a 130 degree centigrade temperature range. It is to be noted that, while an optical fiber bend radius of approximately 2.5 centimeters provides a significant reduction in wavelength ripple as compared to the prior art bend radius of 1.9 cm, any increase in the radius of an existing curved section of optical fiber in a fiber optic gyroscope light source should provide a corresponding decrease in the wavelength ripple caused by that particular section.

Figure 4 depicts a typical waveform 400 of the light generated by fiber optic light source after having been filtered by 980 nm filter 110 and spectrum-shifted by erbium doped fiber 130. As shown in Figure 4, waveform 400 has a bimodal spectrum with peaks 402 and 401 located at approximately 1531 nm and 1560 nm, respectively. Attenuation of the 1531 nm spectral component 402 by fiber Bragg band reject filter 150 further reduces the amount of wavelength ripple present in the output 170 of fiber optic light source 100.

It is to be understood that the claimed invention is not limited to the description of the preferred embodiment, but encompasses other modifications and alterations within the scope and spirit of the inventive concept.

CLAIMS

1. A method for reducing wavelength ripple in a fiber optic light source used in a fiber optic gyroscope, wherein said fiber optic light source includes a wavelength division multiplexer having a first curved section of optical fiber and a second curved section of optical fiber connected thereto, said method comprising the step of:

substantially increasing the radius of each said curved section of optical fiber connected to said wavelength division multiplexer in said fiber optic light source.

2. The method of claim 1, wherein said first curved section of optical fiber and said second curved section of optical fiber are substantially semi-circular.

3. The method of claim 2, wherein the radii of said first curved section of optical fiber and said second curved section of optical fiber are each increased from a radius of less than 2 centimeters to a radius of at least 2.5 centimeters.

4. The method of claim 3, wherein the radii of said first curved section of optical fiber and said second curved section of optical fiber are increased by at least 25 percent.

5. The method of claim 2, wherein said first curved section of optical fiber and said second curved section of optical fiber are each connected to different instances of erbium doped fiber.

6. A method for manufacturing a fiber optic light source used in a fiber optic gyroscope, wherein said fiber optic light source includes a wavelength division multiplexer having a first curved section of optical fiber and a second curved section of optical fiber connected thereto, said method comprising the step of:

constructing said fiber optic light source from a design which has been modified to substantially increase the radius of said first curved section of optical fiber and said second curved section of optical fiber.

7. A method for reducing wavelength ripple in a fiber optic light source used in a fiber optic gyroscope comprising the step of:

replacing an existing, substantially semi-circular section of optical fiber in said fiber optic light source with a replacement section of said optical fiber having substantially greater radius than said existing section.

8. The method of claim 7, wherein said substantially greater radius is at least 25% greater than that of said existing, substantially semi-circular section.

9. A method for reducing wavelength ripple in a fiber optic light source used in a fiber optic gyroscope using a fiber light source having a bimodal output spectrum, wherein said light source includes an erbium doped fiber spectrum-shaping filter and an optical isolator, the method comprising the step of:

filtering light emitted from said fiber optic light source by inserting, between said spectrum-shaping filter and said optical isolator, a band reject filter having a high attenuation in a frequency range centered on a frequency of a secondary spectral peak in said bimodal spectrum, thereby reducing said wavelength ripple by attenuating light comprising said secondary spectral peak.

10. A method for reducing wavelength ripple in a fiber optic light source used in a fiber optic gyroscope comprising the steps of:

replacing an existing section of optical fiber comprising an essentially semi-circular section of a fiber optic light source in said fiber optic light source with a replacement section of said optical fiber, wherein said replacement section has a radius at least 25 percent greater than said existing section; and

filtering light emitted from said fiber optic light source by inserting, in said optical path, a band reject filter having a high attenuation in a frequency range centered on a frequency of a secondary spectral peak in said bimodal spectrum, wherein light comprising said secondary spectral peak interacts with light comprising a primary spectral peak in said bimodal spectrum to cause said wavelength ripple.

11. A fiber optic light source used in a fiber optic gyroscope, wherein said light source includes a wavelength division multiplexer and two semi-circular optical fiber sections each of which is connected to a section of erbium doped fiber, and wherein:

each of said two semi-circular optical fiber sections has a radius of at least 2.5 centimeters.

12. A fiber optic light source used in a fiber optic gyroscope, wherein said light source includes a wavelength division multiplexer and an optical coupler, and wherein said light source generates a bimodal spectrum having a spurious spectral peak, said light source comprising:

a fiber Bragg grating band reject filter located between said wavelength division multiplexer and said optical coupler, wherein said band reject filter is selected to attenuate aid spurious spectral peak, thereby reducing wavelength ripple in the output of said light source.

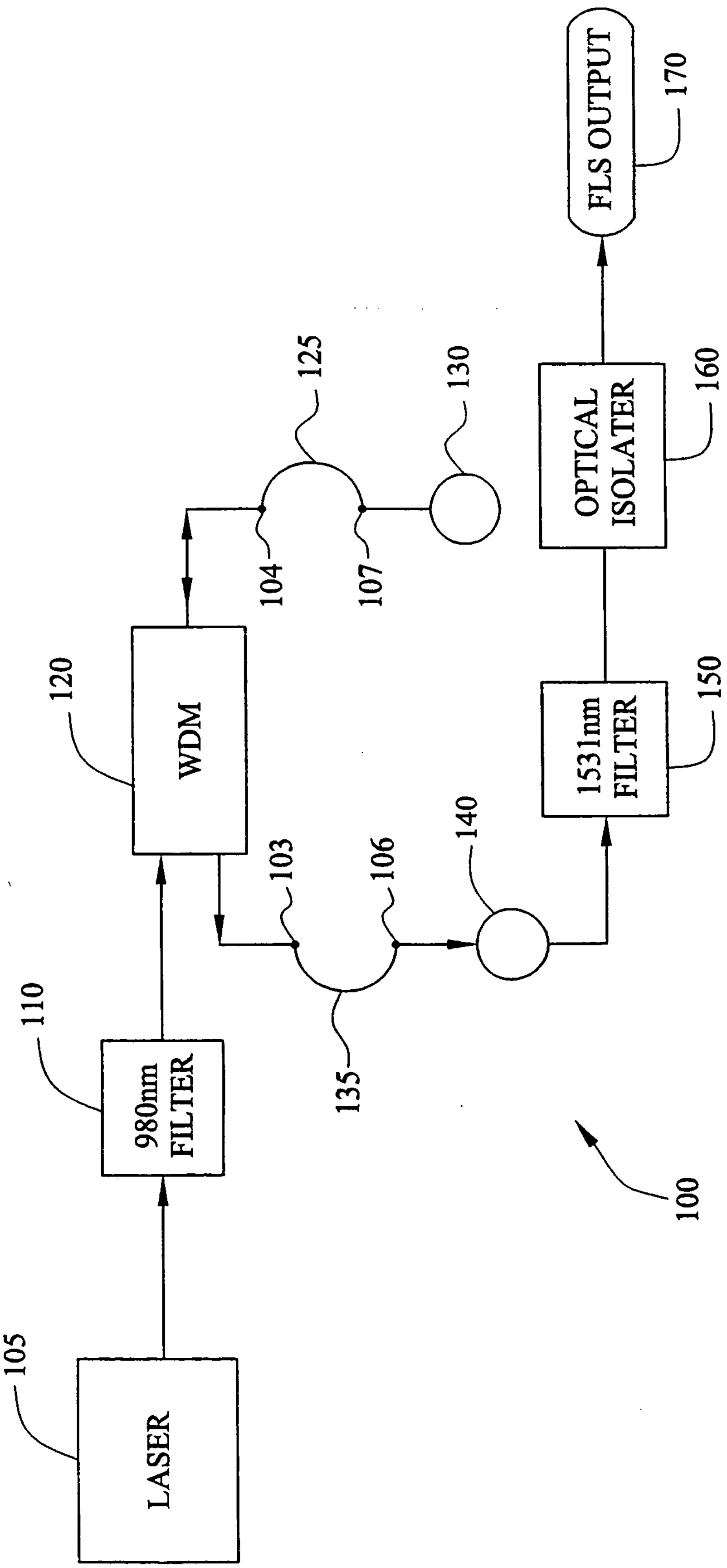
LASER
105
980nm FILTER
110
WDM
120
104
107
125
130
103
106
135
140
1531nm FILTER
150
OPTICAL ISOLATER
160
FLS OUTPUT
170
100

Fig. 1

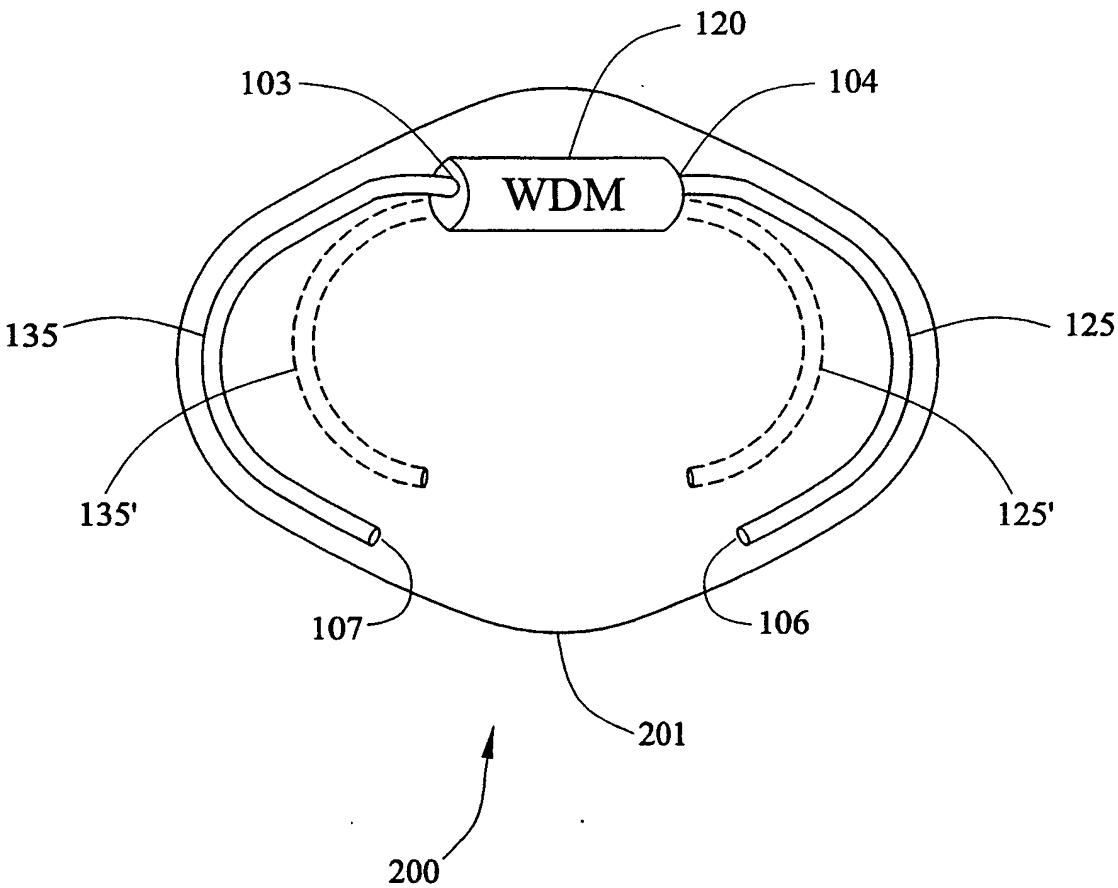

Fig.2

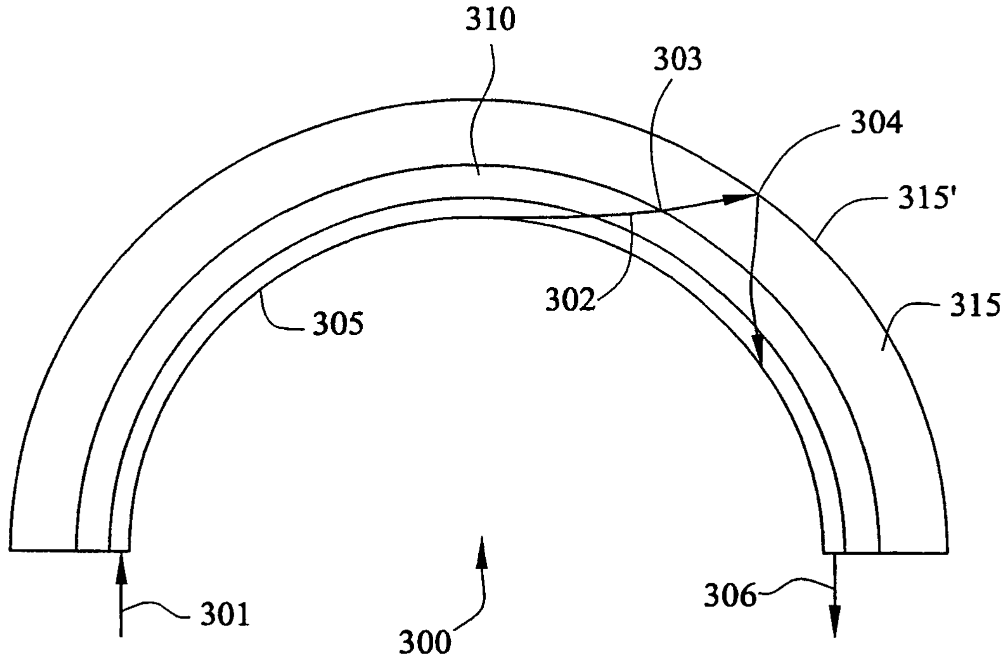

Fig.3

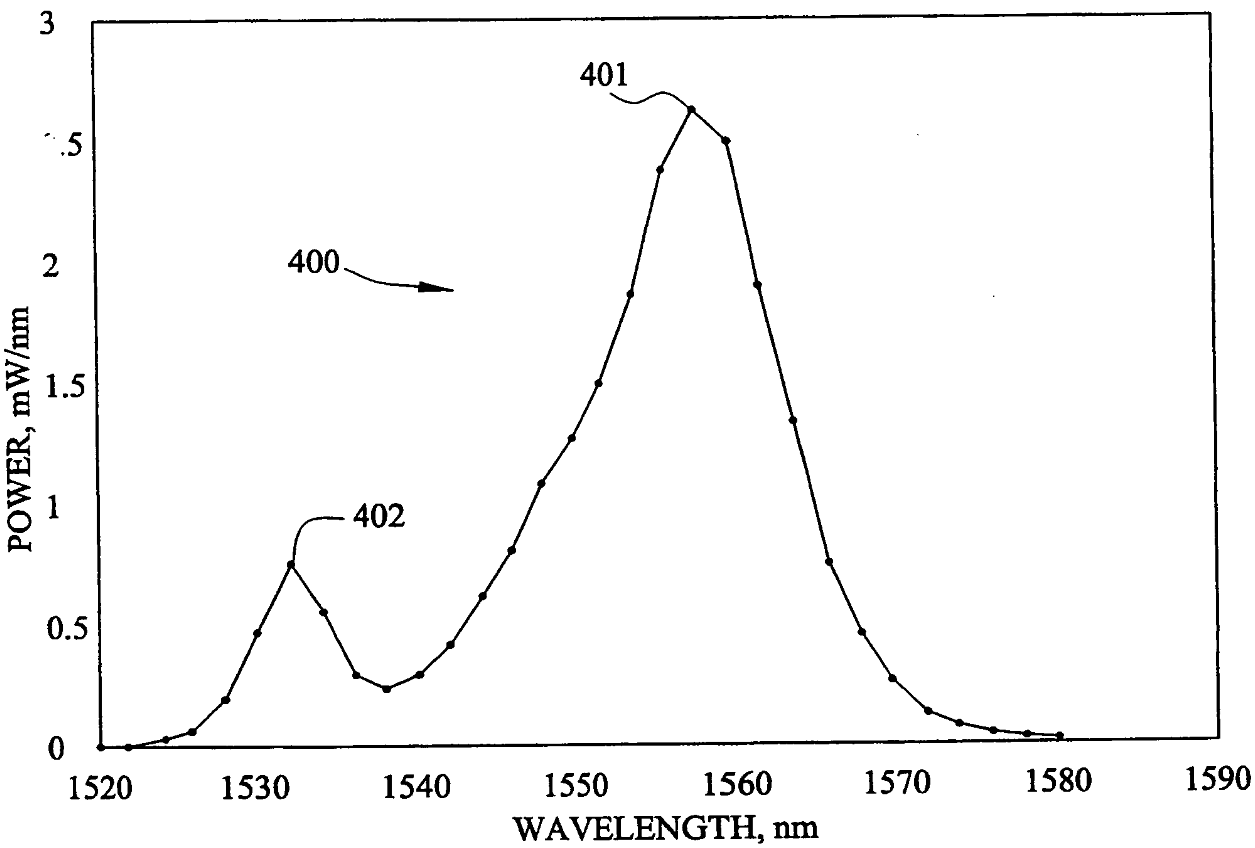
3
2.5
2
1.5
1
0.5
0
POWER, mW/nm
401
400
402
1520
1530
1540
1550
1560
1570
1580
1590
WAVELENGTH, nm

Fig. 4

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01C19/72 H01S3/067

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01C H01S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
16 June 2000	26/06/2000

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